National Aeronautics and Space Administration

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SPACE LAUNCH SYSTEM

2022 AIAA Aviation Forum

Experimental Identification of Bistable Flow States on the Space Launch System at Liftoff Conditions

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www.nasa.gov/sls

OUTLINE

I. Project Background

II. Problem

III. Discussion of Results

IV. Summary

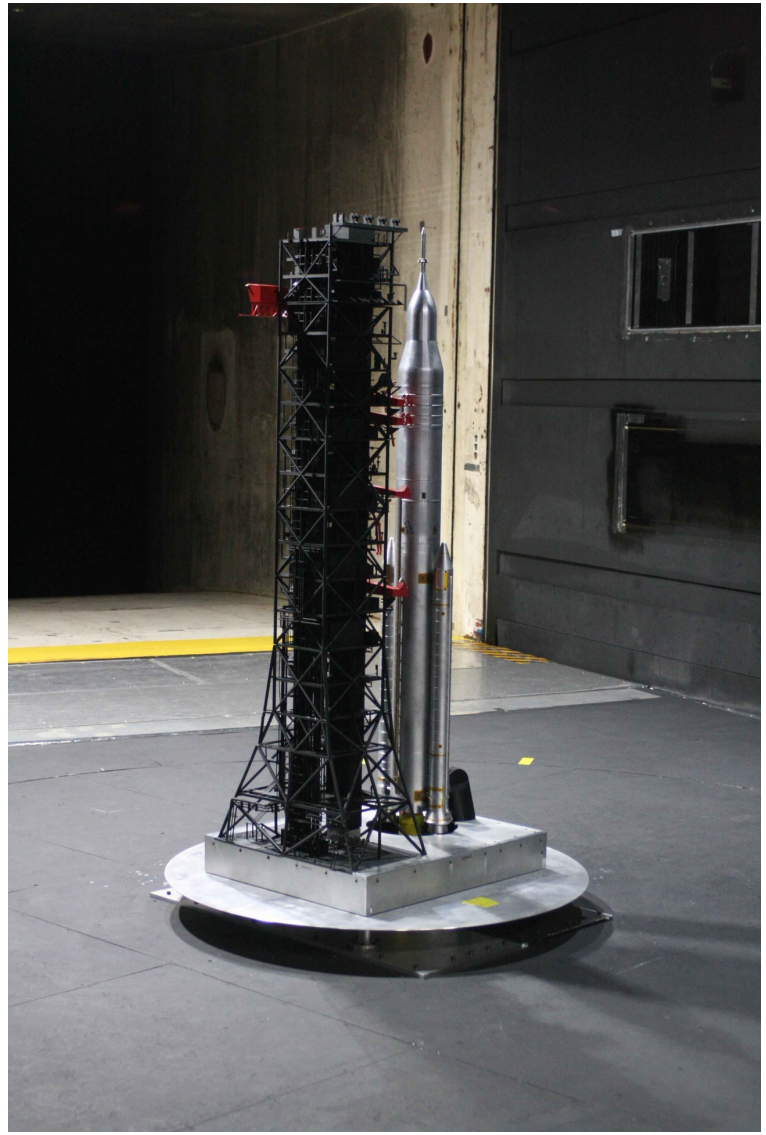
PROJECT BACKGROUND

- **NASA Langley 14- by 22-Foot Subsonic Tunnel Test #657 conducted in 2021 for the Space Launch System (SLS) Program**
  - **Main Objectives:**
    - Gather aerodynamic data at subsonic conditions to generate liftoff and transition (LOT) database for SLS Block 1B Crew and SLS Block 1B Cargo
    - Gather aerodynamic data at subsonic conditions to generate ground wind loads database for SLS Block 1B Crew and Mobile Launcher 2 (ML-2)
- **~240 runs completed, model scale = 1.75%**
- **CUI/ITAR Disclaimer – Ordinate Axis values not shown**

PROJECT BACKGROUND

- **Collected Data Types:**
  - 6-component force & moment measurements on various bodies:
    - Full-stack vehicle, each Solid Rocket Booster (SRB), ML-2 base
  - Individual "Tier" sections of the ML-2
  - Static Surface Pressures (vehicle)
  - Dynamic Surface Pressures (vehicle)

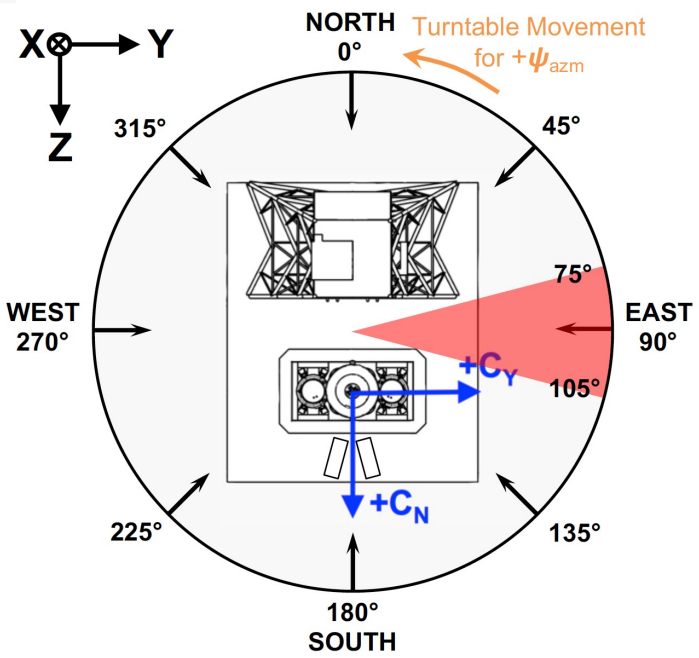
Block 1B Cargo w/ ML-2



Block 1B Crew w/ ML-2

PROJECT BACKGROUND

- ψ_{azm} Definition
- Aero Coefficient Definition

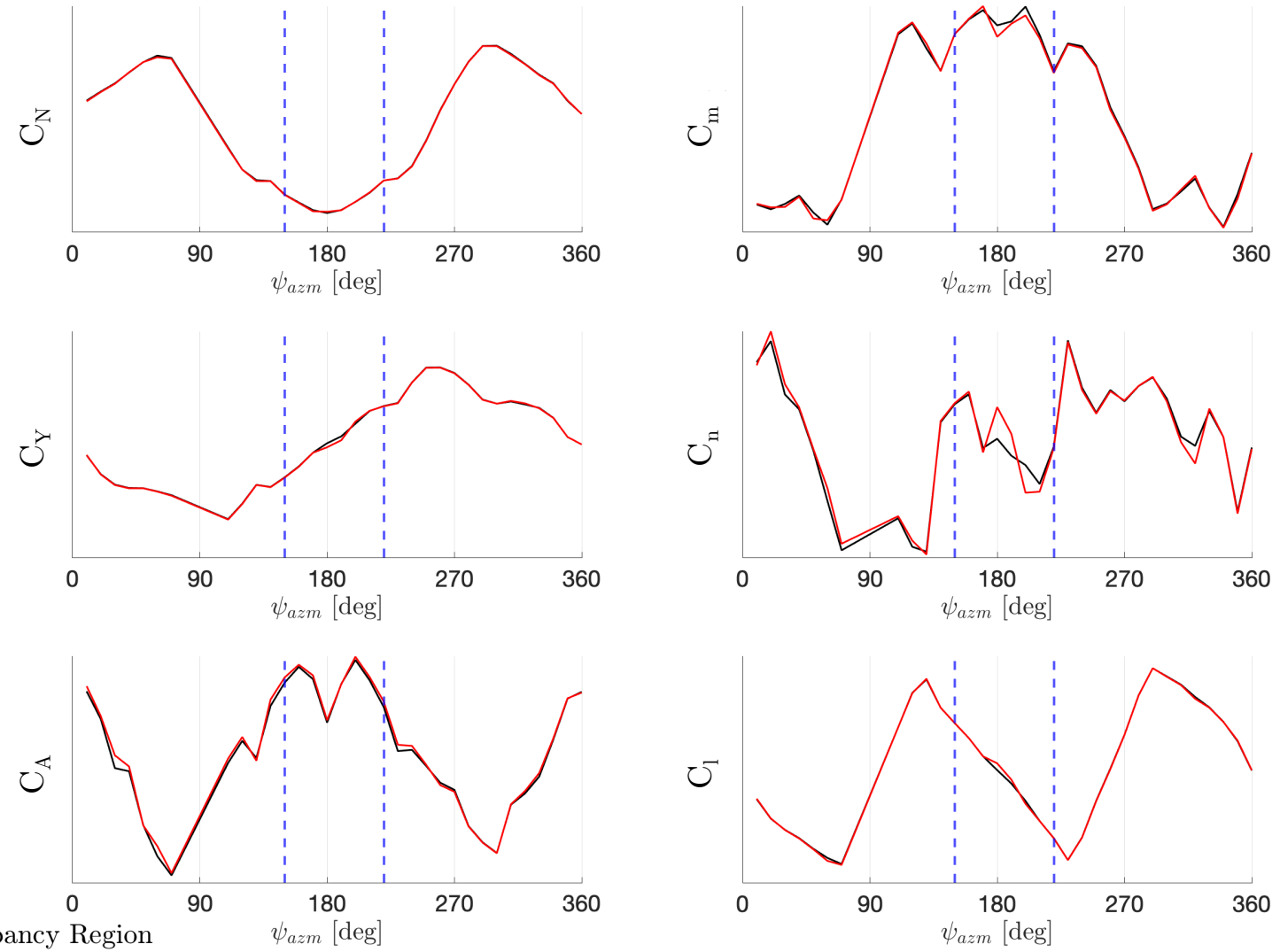


Fixed View (video)

Rotating View (video)

PROBLEM

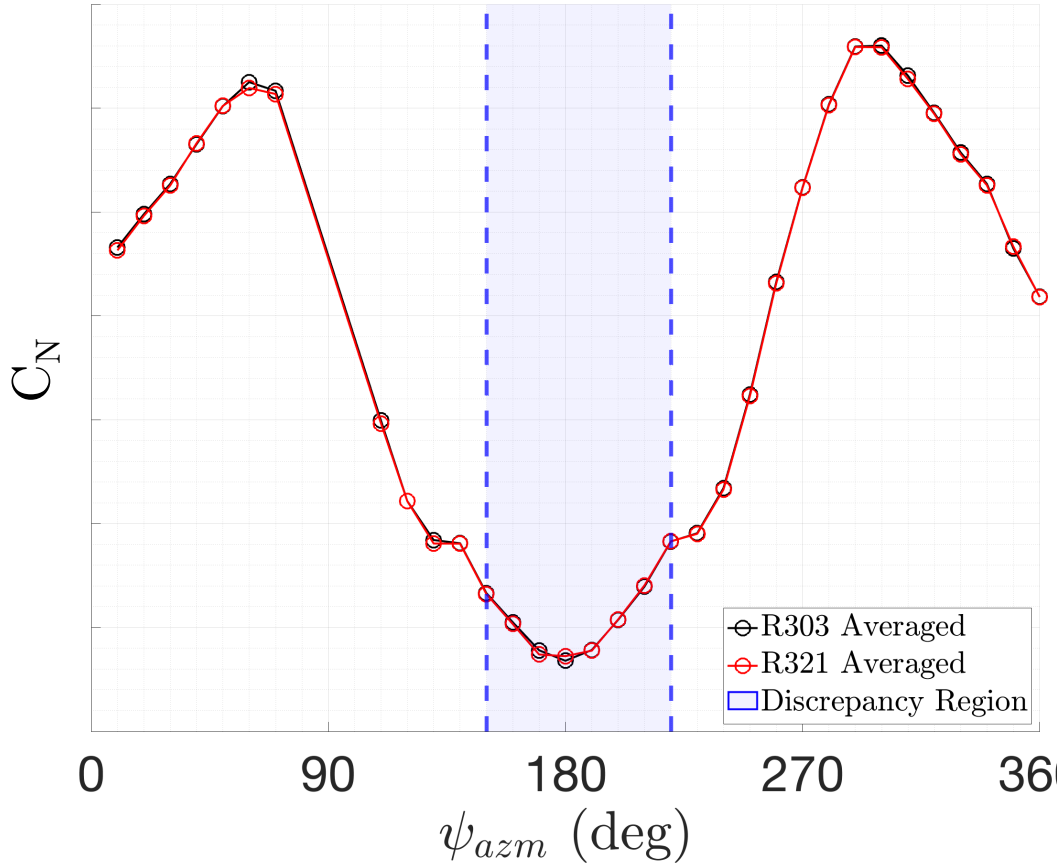
- **Repeatability discrepancies discovered during Liftoff testing**
  - Most notable between ψ_{azm} values of 150° and 220°
  - C_Y, C_n, C_m, and C_l particularly affected
  - Differences occurred on both SLS configurations, with ML-2 both present and removed

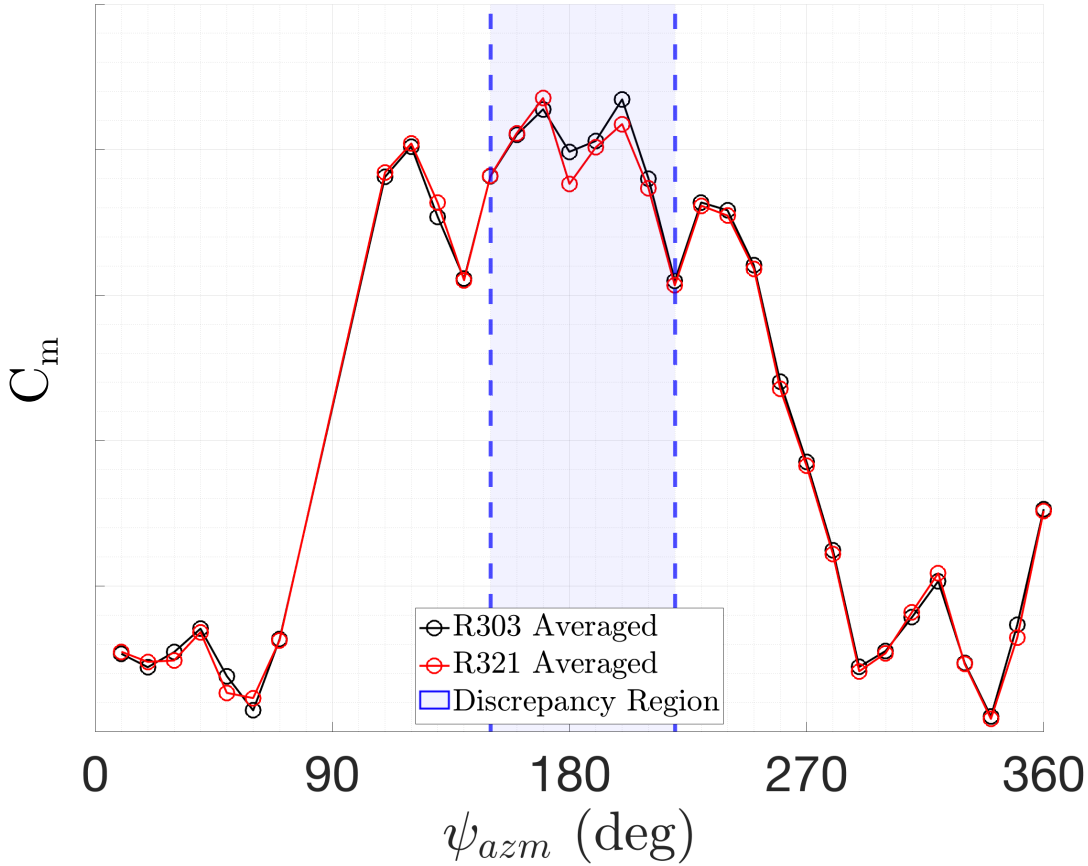


Test 657, Full-Stack, SLS Block 1B Crew, ML-2 Installed, q_∞ = 50 psf

PROBLEM

C_N and C_m

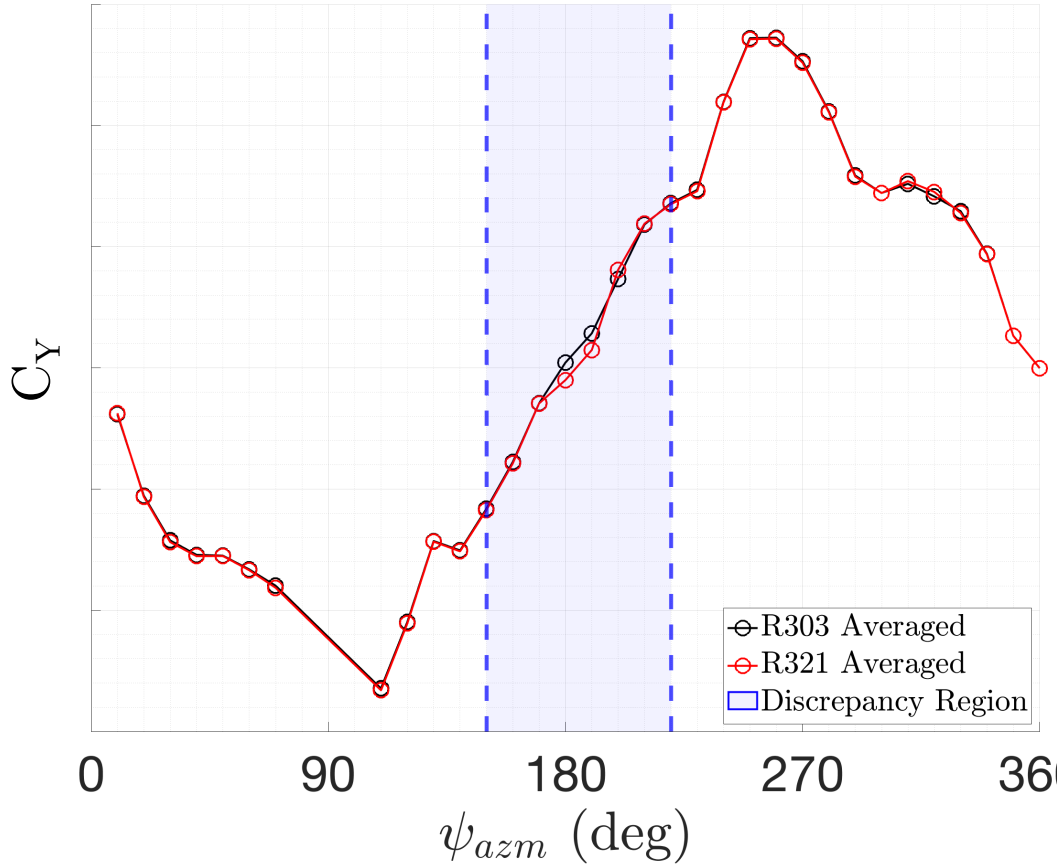


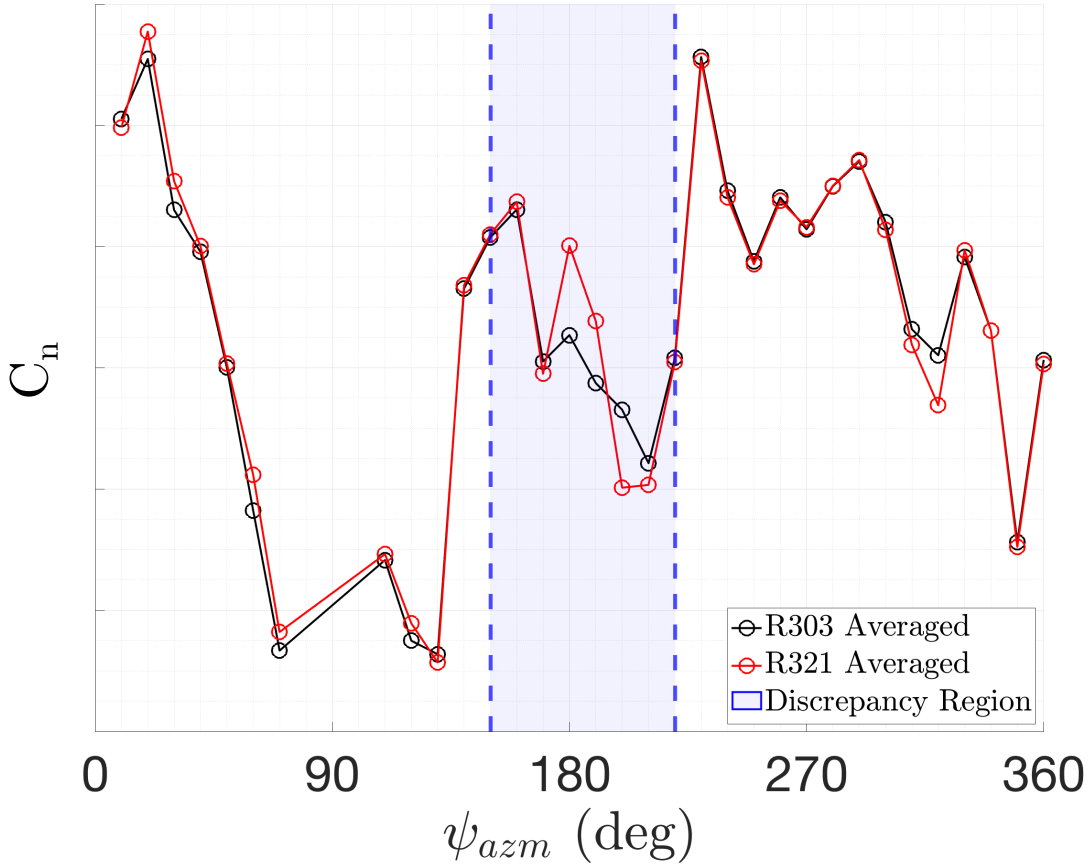


Test 657, Full-Stack, SLS Block 1B Crew, ML-2 Installed, q_∞ = 50 psf

PROBLEM

C_Y and C_n

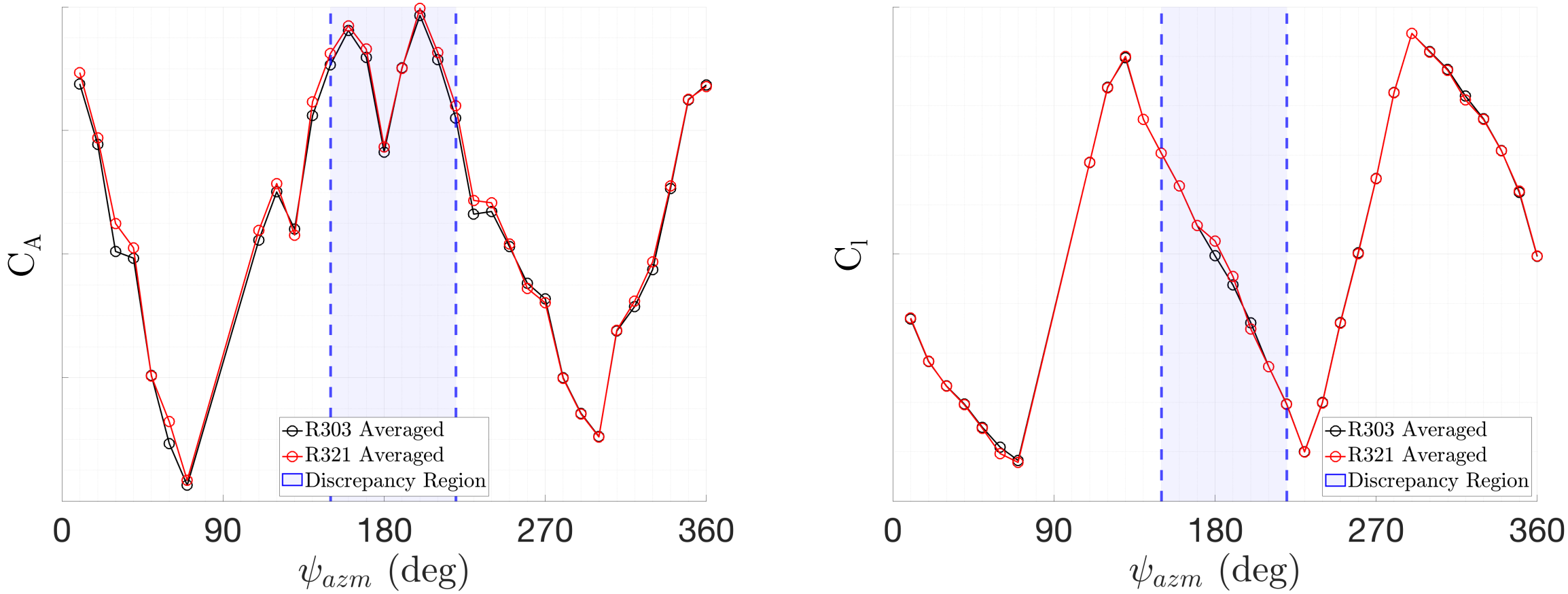




Test 657, Full-Stack, SLS Block 1B Crew, ML-2 Installed, q_∞ = 50 psf

PROBLEM

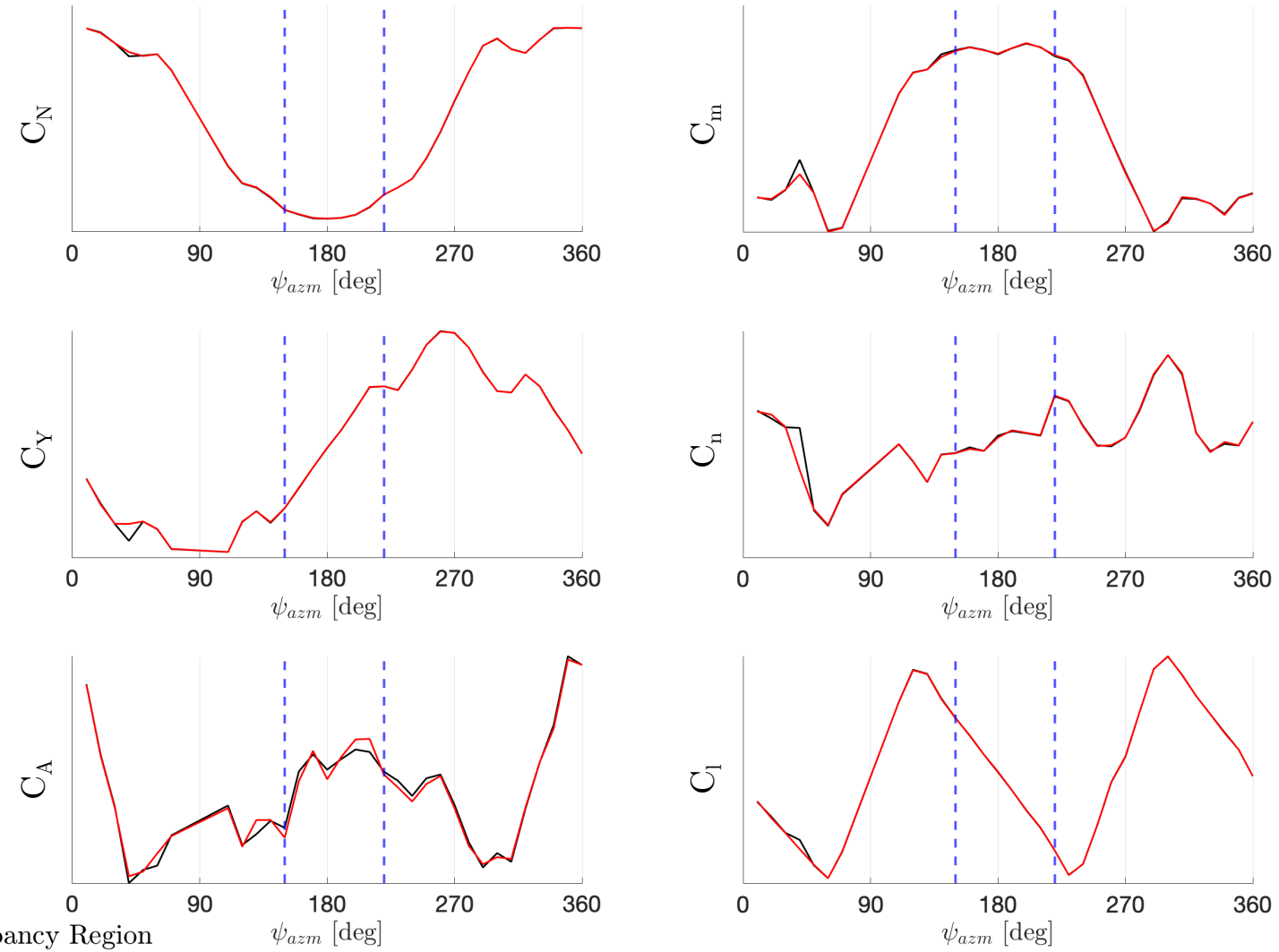
- C_A and C_l



Test 657, Full-Stack, SLS Block 1B Crew, ML-2 Installed, q_∞ = 50 psf

PROBLEM

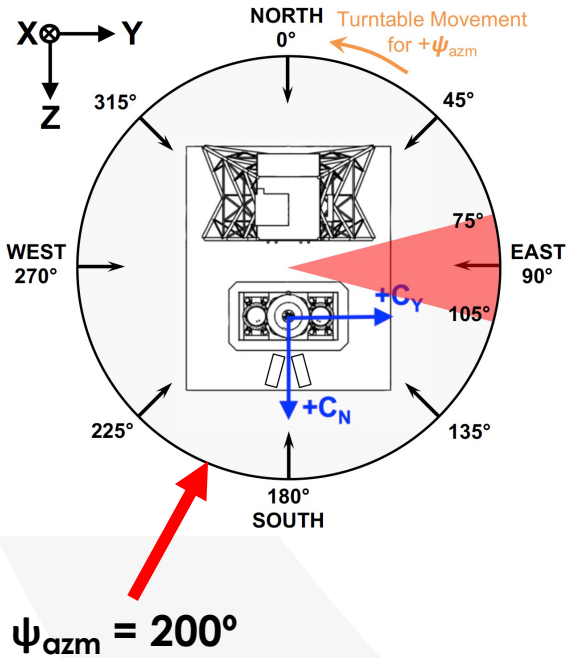
- **Repeatability discrepancies not present in previous tests**
  - Test 633 repeated well across all ψ_{azm} values
  - Factors such as hysteresis, temperature differences, tower presence ruled out



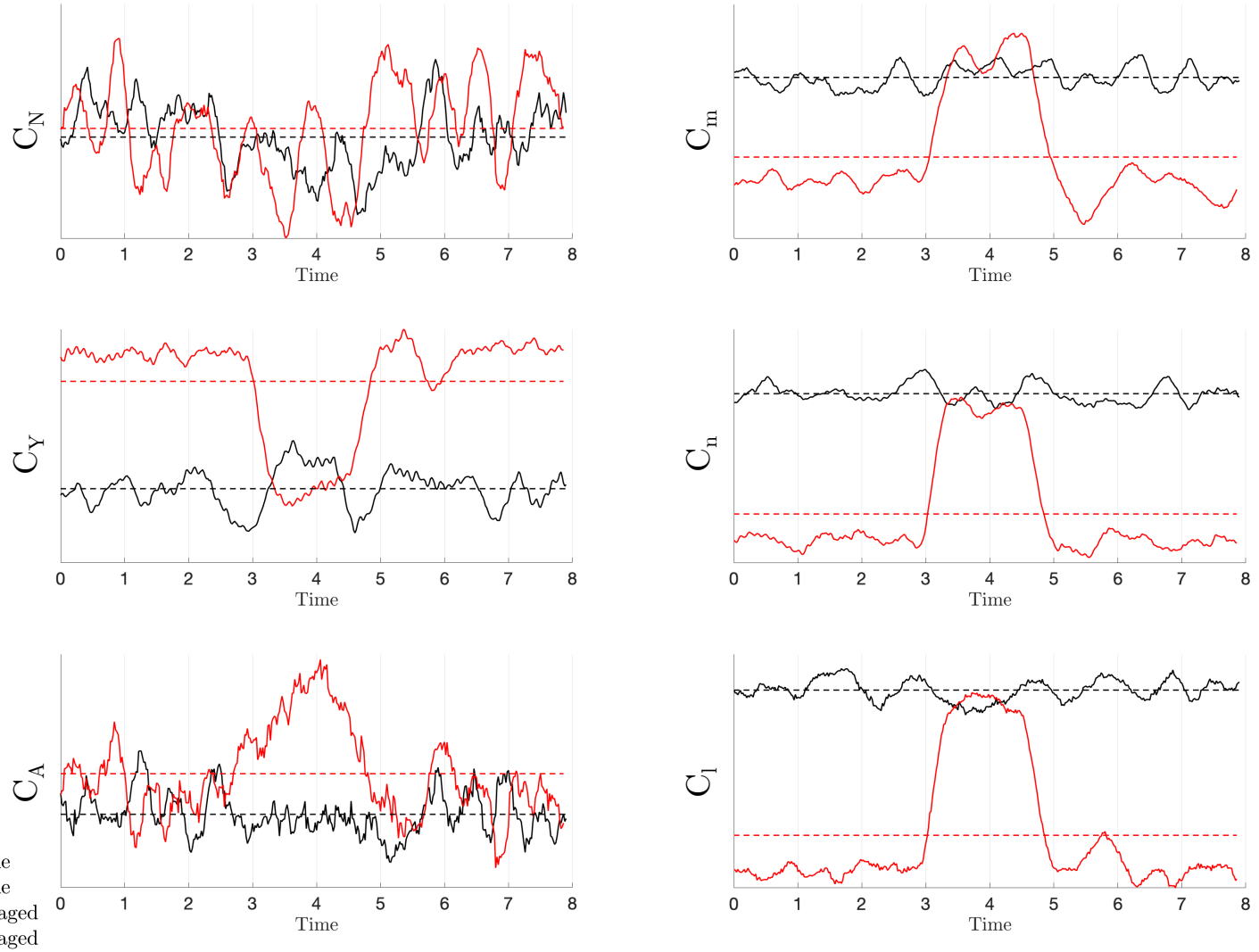
Test 633, Full-Stack, SLS Block 1B Crew, ML-1 Installed, q_∞ = 50 psf

DISCUSSION OF RESULTS

- **Time-dependent data shows bistable state-switching behavior between t ≅ 3 and 5 seconds**



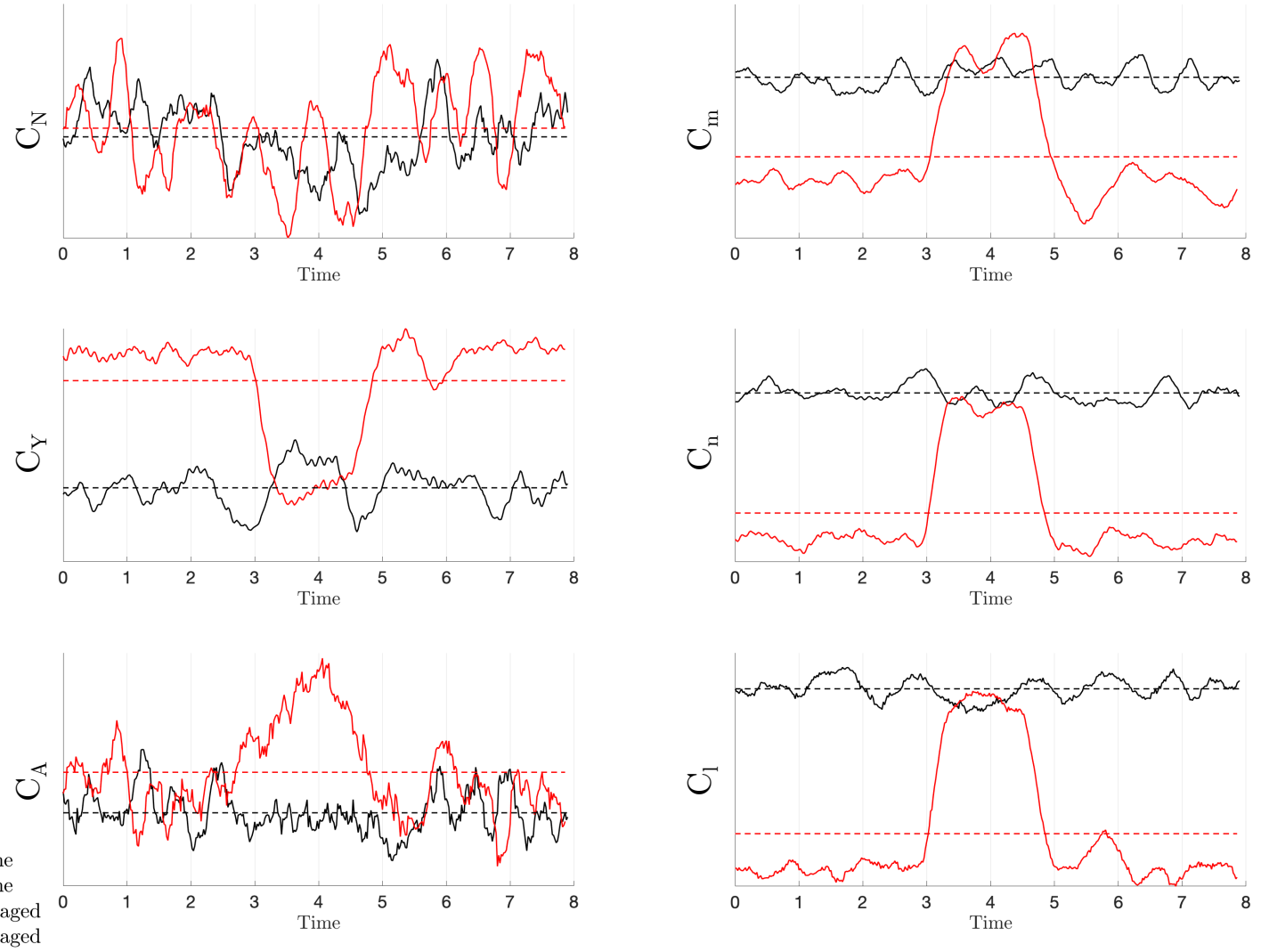
ψ_{azm} = 200°



Test 657, Full-Stack, SLS Block 1B Crew, ML-2 Installed, ψ_{azm} = 200°, q_∞ = 50 psf

DISCUSSION OF RESULTS

- **Time-dependent data shows bistable state-switching behavior between t ≅ 3 and 5 seconds**
  - Run 321 forces and moments 'snap' to the same values as Run 303 before snapping back
  - Some, but not all repeat runs capture this behavior – appears to be random

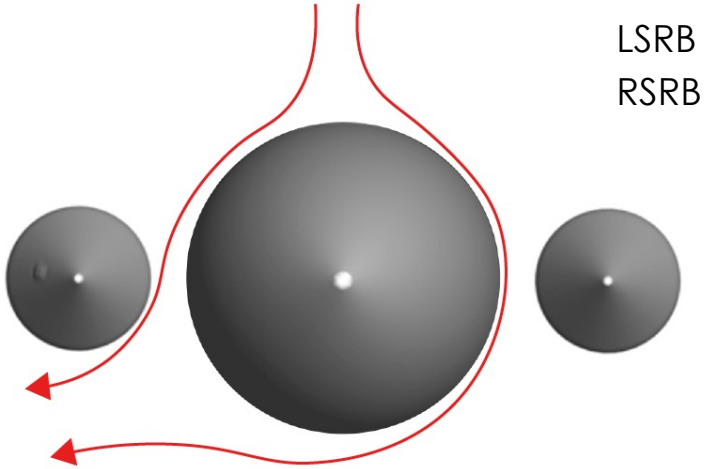


Test 657, Full-Stack, SLS Block 1B Crew, ML-2 Installed, ψ_{azm} = 200°, q_∞ = 50 psf

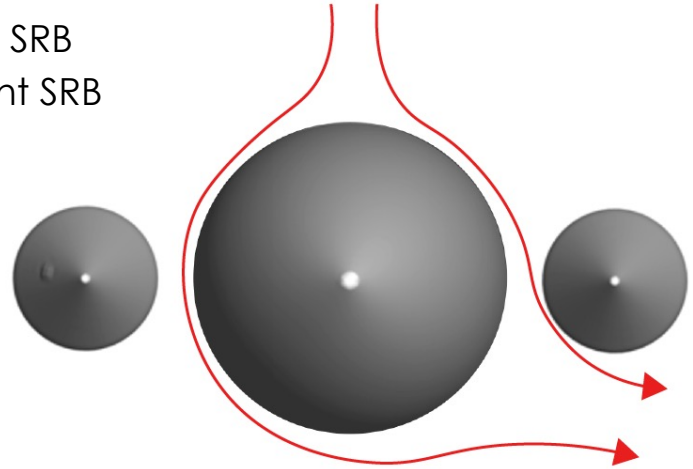
DISCUSSION OF RESULTS

- **Coandă effect proposed as potential cause for this behavior**
  - Gap flow physics lead to two bistable states at head-on wind azimuths
  - States switch randomly throughout 8-second datapoint sampling duration

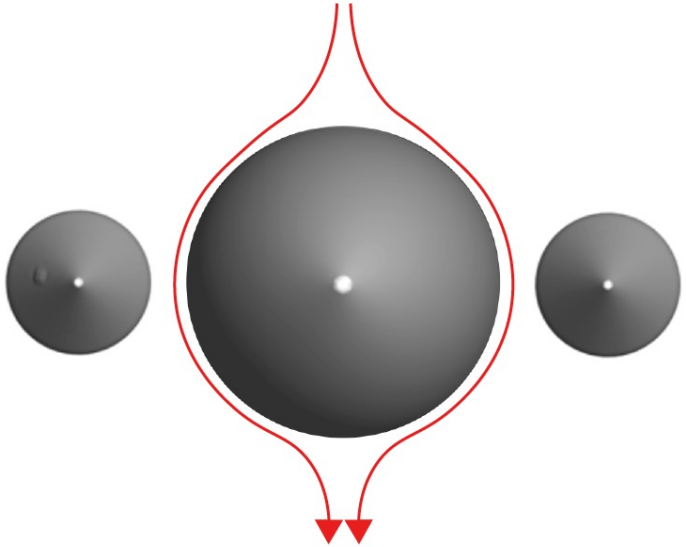
LSRB = Left SRB
RSRB = Right SRB



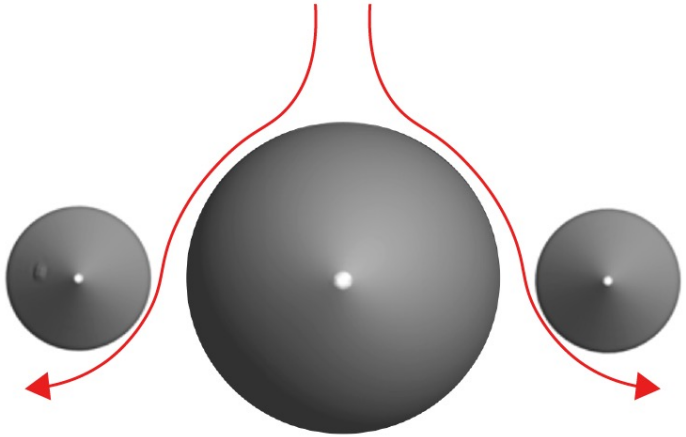
Attached to Centerbody, LSRB



Attached to Centerbody, RSRB



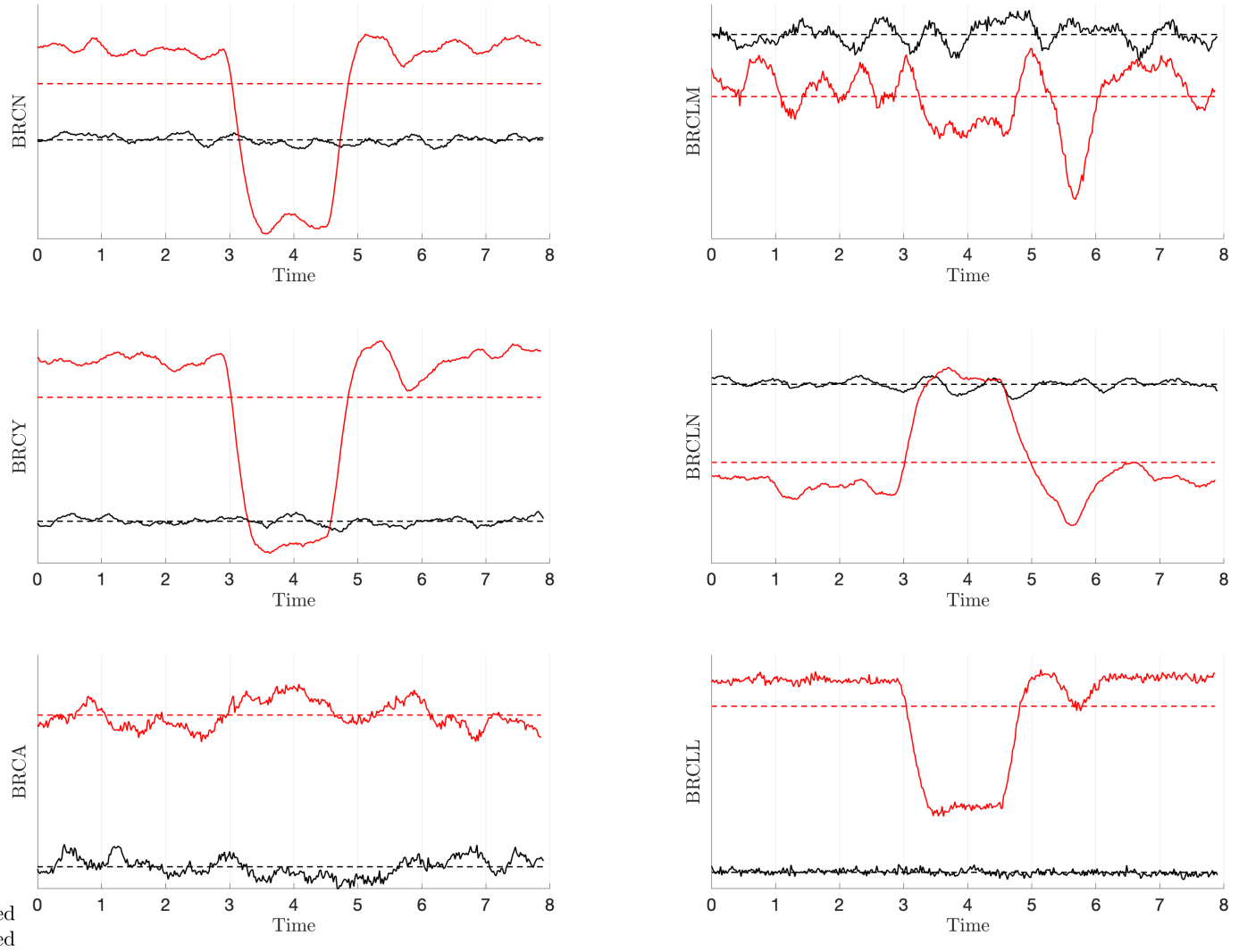
Attached to Centerbody



Attached to LSRB, RSRB

DISCUSSION OF RESULTS

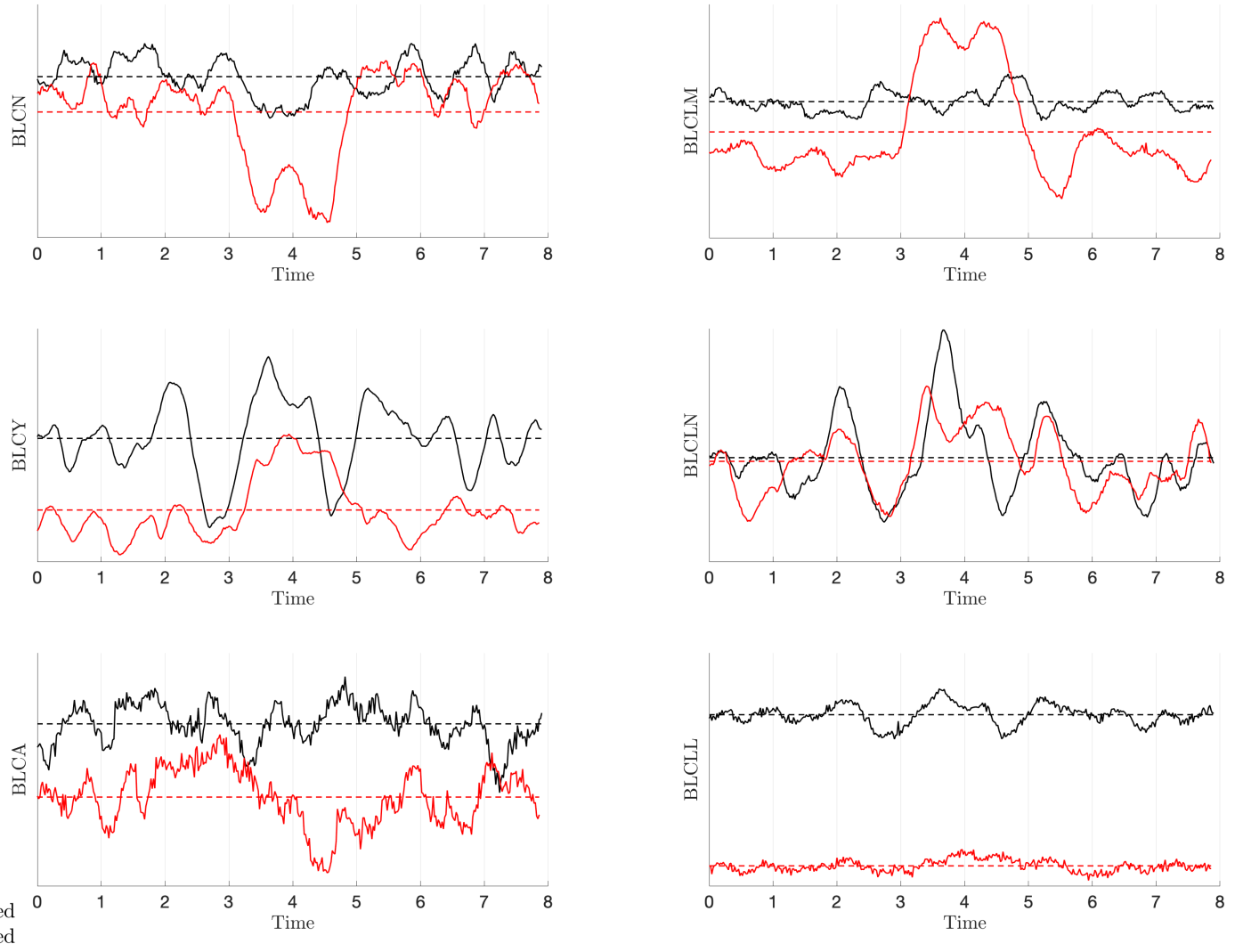
- **RSRB time-dependent data shows similar bistable behavior to full-stack data**
  - Noticeable jumps occur between t ≅ 3 and 5 seconds
  - Normal force (BRCN), pitching moment (BRCLM) behave slightly different to full-stack counterparts



Test 657, RSRB, SLS Block 1B Crew, ML-2 Installed, ψ_{azm} = 200°, q_∞ = 50 psf

DISCUSSION OF RESULTS

- **LSRB time-dependent data shows slightly different behavior**
  - Only noticeable jumps occur in normal force (BLCN) and pitching moment (BLCLM)
  - May indicate partial state switch on left booster rather than full

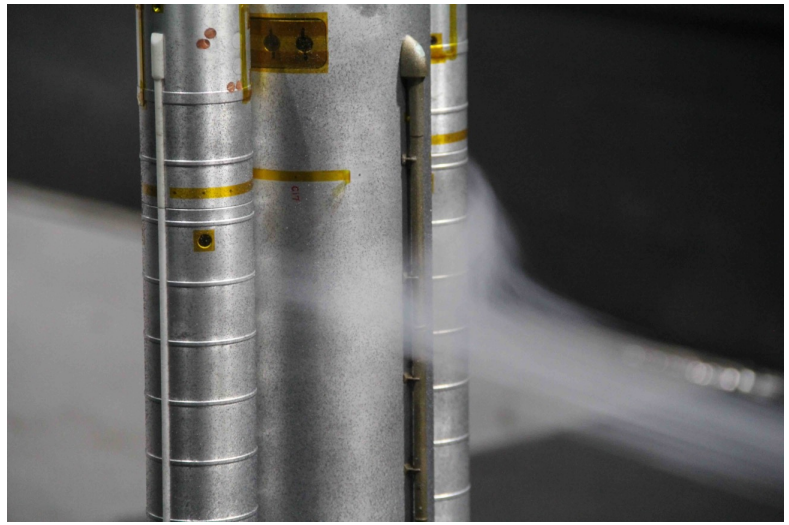


Test 657, LSRB, SLS Block 1B Crew, ML-2 Installed, ψ_{azm} = 200°, q_∞ = 50 psf

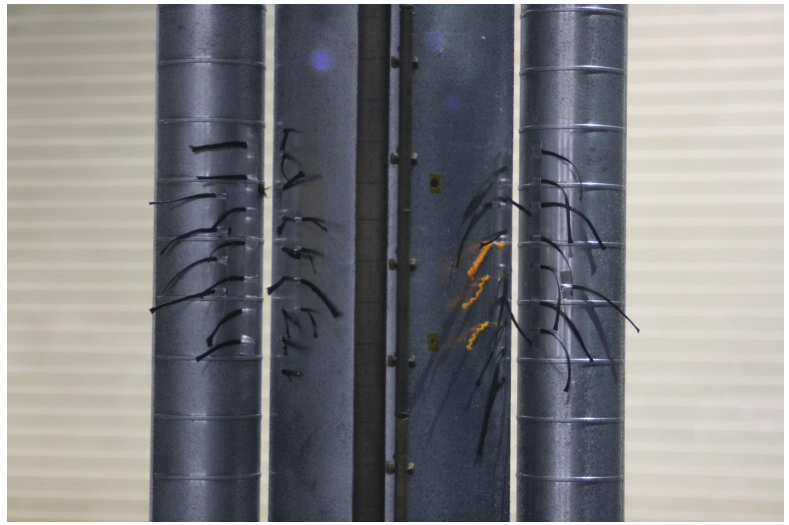
DISCUSSION OF RESULTS

- **Smoke flow visualization performed to visually capture state-switching**
  - ML-2 and launch platform removed, model tufted downstream of SRB gaps
  - Tunnel operated at q_∞ = 3.5 psf for safety

Smoke flow setup



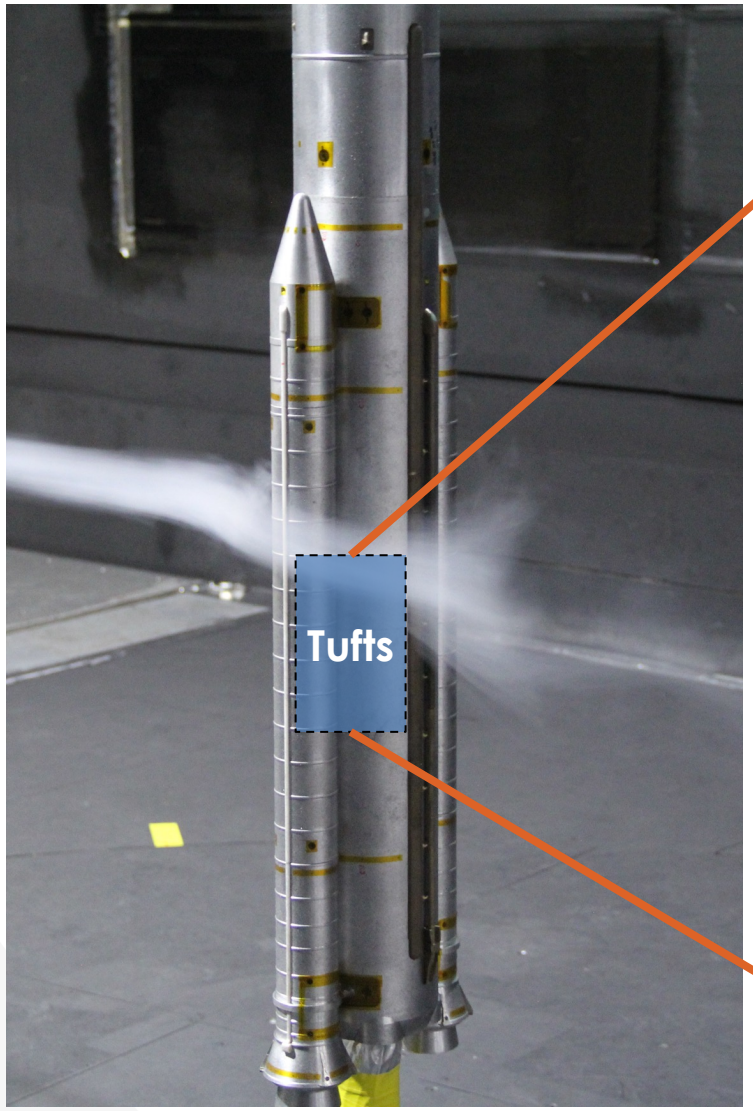
Smoke flow applied to SRB gaps



Tufts setup

DISCUSSION OF RESULTS

Wind Direction



Video

SUMMARY

- **SLS repeat run discrepancies at liftoff conditions investigated**
  - Coandă effect proposed as potential cause for bistable behavior observed in time-dependent data and smoke flow runs
  - Difficult to capture all four flow states individually, recommended to factor this into uncertainty quantification efforts

- **Next steps**
  - Perform CFD at conditions of interest in attempt to computationally replicate bistable behavior
  - Run more wind tunnel tests at conditions of interest to further understand behavior -> Wind Induced Oscillations test scheduled late 2022

QUESTIONS